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Challenges for Management of the Fisheries Resources, Biodiversity and Environment of Lake Victoria

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Fisheries Resources Research Institute

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IDRC CANADA

UGANDA KENYA TANZANIA

LAKE VICTORIA ENVIRONMENT MANAGEMENT PROJECT LAVEMP FOR MAXIMUM SUSTAINABLE BENEFITS

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7.2. Management of Water hyacinth, *Eichhornia crassipes* in Lake Victoria Basin

T. K. Twongo and F. M. Wanda

Introduction

Water hyacinth is a free-floating waterweed native to the Amazon River Basin in South America. In its native range, water hyacinth is not an environmental problem, although the weed is one of the most invasive alien plants in freshwater environments. Water hyacinth has the potential to become invasive through fast vegetative reproduction and rapid growth to accumulate huge biomass and extensive cover in freshwater environments.

Over the last 150 years water hyacinth has invaded most countries in the tropics and sub-tropics, introduced by man, mainly for ornamental purposes. Such introductions led to the infestation of most freshwater-ways in the southern United States of America, parts of Australia, the pacific islands, and most countries in Asia and Africa.

The extensive tightly packed mats of water hyacinth are often associated with devastating socio-economic and environmental impacts. Invasion by the weed has, therefore, often generated urgent costly problems associated with the weed biomass and its management. A classic example of such problems was triggered by the invasion and proliferation of water hyacinth in the Lake Victoria Basin during the 1980s (Freilink 1989, Taylor 1993, Twongo *et al.,* 1995). The weed infestation marked the beginning of a decade of intensive and systematic campaign by the three riparian states (Kenya, Tanzania and Uganda) to bring weed proliferation under control. The discussions in this Chapter span over ten years of dealing with the challenges paused by the imperative to manage infestations of water hyacinth in the Lake Victoria Basin. The challenges included the need to understand the dynamics of water hyacinth infestation; its distribution, proliferation and impact modalities; and the development and implementation of appropriate weed control strategies and options. Most specific examples were taken from the Ugandan experience (NARO, 2002).

Invasion and distribution of Water hyacinth

Water hyacinth is said to have invaded the African continent for the first time via the River Nile Basin in Egypt between 1872 and 1892 (Gopal and Sharma 1981). It is, however, unlikely that the initial invasion in Egypt was the source of subsequent outbreaks in most other parts of Africa, including East Africa because sustained upstream translocation of the weed along the Nile would have been difficult. Water hyacinth was first reported in the natural water systems of East Africa in Tanzania's River Sigi in 1955 and entered the Pangani River around 1959. The waterweed was reported in Lake Kyoga (Uganda), Lake Naivasha (Kenya) and Lake Victoria (shared by Kenya, Tanzania and Uganda), at about the same time in the late 1980s (Hurley 1993). The source of the infestations in the natural water bodies of East Africa was, probably, potted ornamental water hyacinth.

The initial infestation with water hyacinth in the natural waterways of the Lake Victoria Basin was traced to the upper watershed of River Kagera; and the likely upstream location of the invasion source was Ruhengeri in northern Rwanda, in a tributary of the Nyabarongo River . Once in the Kagera River system, establishment and distribution of water hyacinth downstream occurred rapidly facilitated by the river current, especially during the rainy season. The weed entered Lake Victoria from River Kagera between 1987 and 1988 (Mallya 1999). The dispersal of water hyacinth along the shores of Lake Victoria was so fast in view of the vast size of the lake (68,800km^2) and the convoluted formation of its shores, particularly along its northern, western and southern margins. The weed was first reported in the Entebbe zone of the lakeshores in Uganda in 1989 (Taylor 1993). Water hyacinth was firmly established in most suitable littoral environments along the shores of Lake Victoria in Uganda by the end of 1991 (Taylor 1993; Twongo 1996). Water hyacinth reached the eastern shores of Lake Victoria in Tanzania during 1990. The weed spread into the Kenya waters (Winam Gulf) of Lake Victoria from Uganda between 1991 and 1992. The infestation was probably distributed along the entire shoreline of Kenya within two years. The rapid spread of water hyacinth around the shores of Lake Victoria was facilitated by a combination of wind patterns including the diurnal land and sea breeze, various local winds and the prevailing winds especially the South East Trade winds (in Uganda); and by water currents.

Proliferation and redistribution of water hyacinth

Proliferation and redistribution of water hyacinth in the Lake Victoria basin was discussed with respect to the processes in the Kagera River, the main lake and other affluent rivers, where infestations do not cover long distances upstream. Nutrients especially phosphorus are known to drive proliferation of waterweeds. Indeed it is often said that the appearance of water weeds especially water hyacinth in a water system, is an indication of enrichment with nutrients. Attempts are made to highlight the link between environmental factors especially the main limiting nutrient, phosphorus, and the proliferation of water hyacinth in the Lake Victoria Basin.

Proliferation and redistribution in the Kagera River

River Kagera, the initial source of water hyacinth infestation in Lake Victoria, has several zones of very active weed proliferation. They include the low lying floodplains between the confluence of the Nyabarongo and the Akanyaru tributaries and the confluence of main Kagera River and the Ruvuvu tributary (also referred to as Ruvubu) in southern Rwanda; the floodplains along the eastern border of Rwanda with Tanzania; and the lower river valley of the Kagera on its final leg to Lake Victoria (Twongo *et al.*, 2002; Fig 7.2.1). Weed proliferation occurs at the low-lying zones of the riverbanks and in the numerous water pools and small lakes strewn about especially in the floodplain zone in southern Rwanda. Proliferation of water hyacinth in River Kagera occurred almost all year round but it was more intense during the drier months when the water level of the river receeded to allow fixed weed mat formations. Large quantities of water hyacinth biomass were continuously dislodged, especially at the onset of the rainy seasons, and translocated downriver. The Kagera River was, therefore, a constant source of large quantities of water hyacinth biomass into Lake Victoria. The magnitude of the biomass was, however, not accurately determined.

Water quality data from various zones of River Kagera suggested that the relatively high content of phosphorus in the river (>25 mg l^{-1} of SRP) was responsible for the continuous proliferation of luxurious water hyacinth (Twongo *et al.*, 2002). Lakes Ihema and Mihindi in the eastern floodplains, which are only temporarily connected to the main river channel during peak floods (see Fig 7.2.1), recorded significantly lower levels of SRP (12 and 11.3mg l^{-1}). The two little lakes had only sparsely distributed stunted water hyacinth mats. The absence of water hyacinth from River Ruvuvu only about 500m from its confluence with the heavily weed infested main Kagera arm (see Fig 7.2.1), was striking. It was attributed to the comparatively much lower conductivity (49.5 $\mu S\ cm^{-1}$) of River Ruvuvu as compared to that of the main Kagera arm (173.3 $\mu S\ cm^{-1}$).

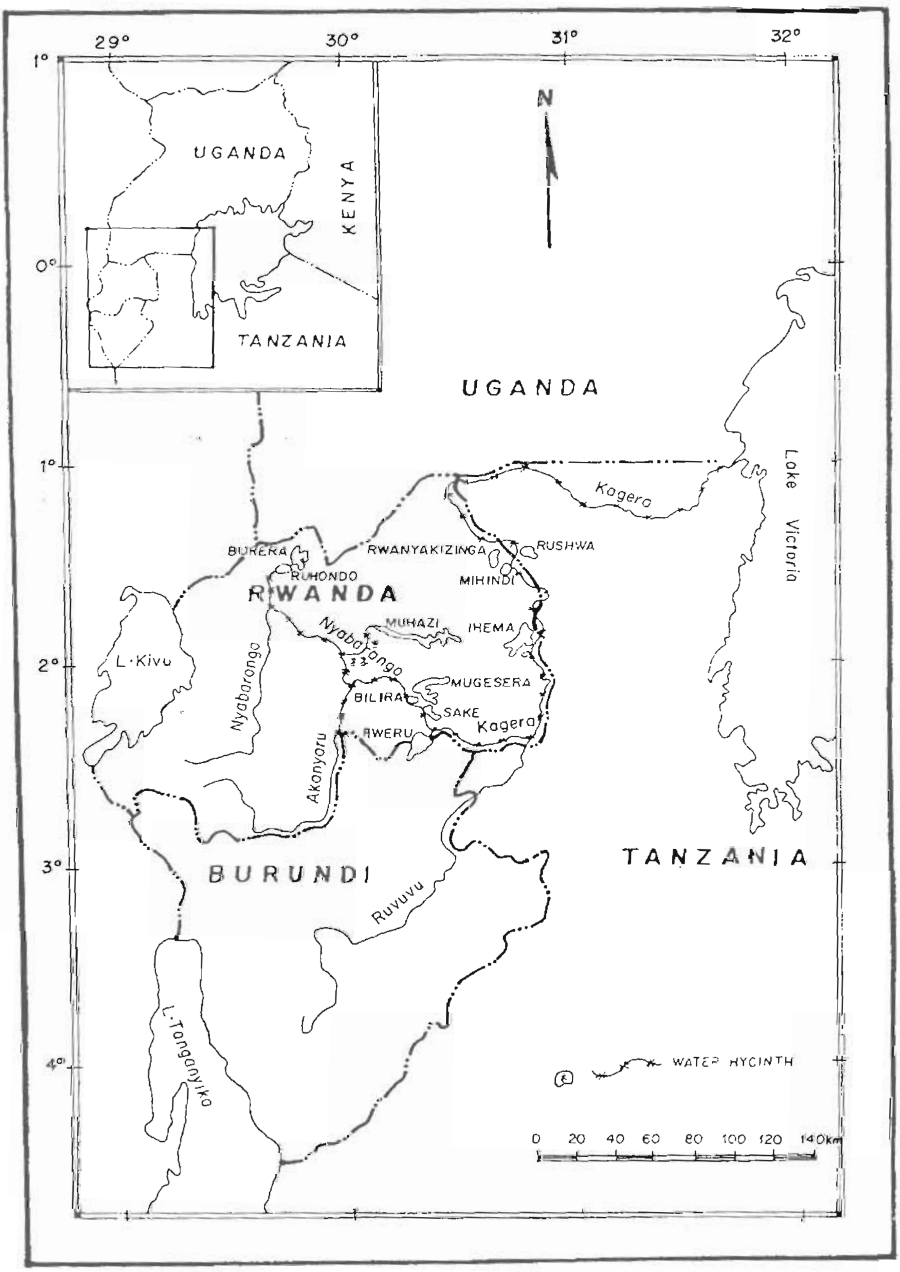

Fig. 7.2.1. The Kagera River showing the distribution of water hyacinth (from Twogo *et al* 2002).

Proliferation and redistribution in Lake Victoria

The numerous sheltered bays and inlets typical of the shoreline of Lake Victoria, especially, in the Ugandan sector, were the initial habitats for widespread establishment and proliferation of water hyacinth (Twongo *et al.*, 1995). In Uganda, these habitats were shallow (< 5 m deep), had soft muddy bottoms rich in organic matter and they were fringed by papyrus (*Cyperus papyrus*). Their environment was typically sheltered from offshore and along the shore winds. The above characterization of the habitats suitable for water hyacinth infestation and proliferation to include papyrus as an emergent indicator macrophyte in the Uganda portion of Lake Victoria facilitated lake-wide extrapolated identification of the potential proliferation zones for the weed from Admiralty Charts of the lake (Twongo *et al.*, 1995; Fig 7.2.2).

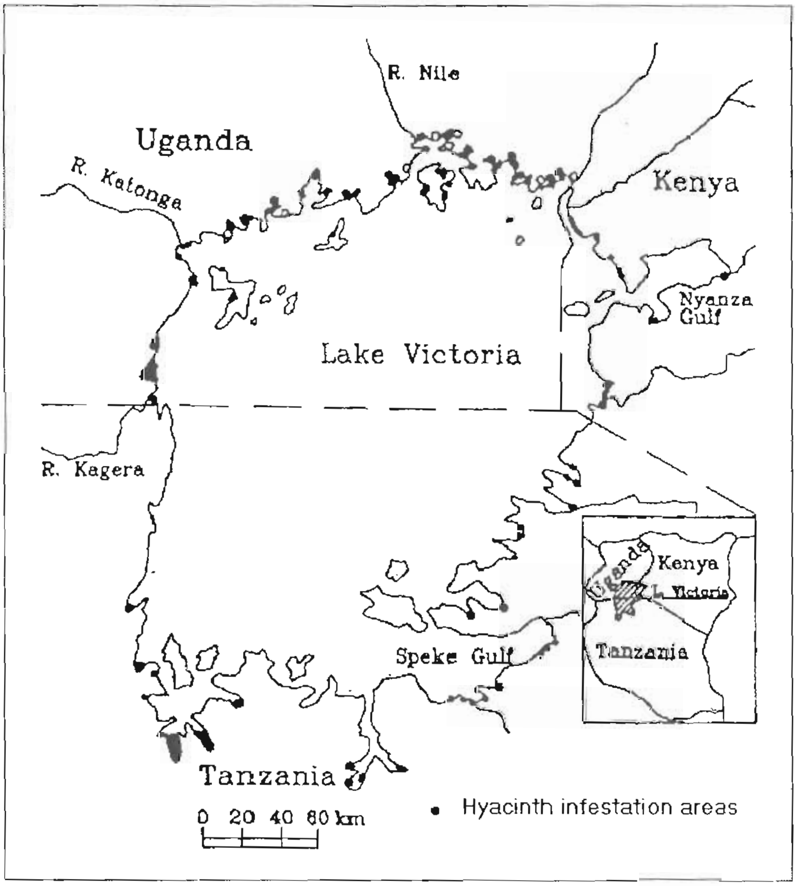

Fig. 7.2.2. Extrapolated potential for establishment and ploriferation of water hyacinth along the shores of Lake Victoria (Modified from Twongo, 1996).

Availability of nutrients in the shallow water hyacinth nurseries located over mud rich in organic debris facilitated rapid weed growth. The luxurious weed mats eventually spilled out of the restricted nurseries and spread laterally along the less sheltered shores and eventually formed firm stationary mats. Lateral and lake-ward expansion of the stationary weed fringes in the Ugandan portion of Lake Victoria continued until 1995 when they averaged 10-5 m in width. At their maximum extent, stationary water hyacinth was estimated to fringe about 80% of the shoreline length in Uganda, and cover an estimated total area of 2200 ha (NARO, 2002). A comparatively limited lateral extent of well-developed stationary fringes of water hyacinth developed along the shores of

Lake Victoria in Kenya and Tanzania, possibly due to the preponderance of hard-bottomed (clay, rocky and sandy) environments. These shores are also relatively open with much fewer sheltered bays and in-lets typical of those in the Ugandan portion of the lake.

Formation of mobile water hyacinth started during the early 1990s when the stationary weed mats along the shores expanded beyond the required shelter threshold provided by shoreline topography. This dynamic aspect signaled the beginning of redistribution of water hyacinth on Lake Victoria. Parts of the weed mats broke away and floated about but these loose plants were often returned by diurnal winds to the shoreline within a given sheltered bay. This process facilitated formation of larger mobile mats. Proliferation of mobile water hyacinth in various bays continued at different rates. Murchison Bay near Kampala was the most efficient weed production centre in Uganda. This well sheltered bay stored most of the weed biomass produced. During the last quarter of every year, gusts of strong winds often associated with thunderstorms, evacuated mobile water hyacinth from the production bays to the open lake. Murchison Bay always contributed the largest weed biomass. The vast expanse of water hyacinth was buffered about the open lake by the waves, through spectacular migrations, which often lasted 1 to 2 weeks (Fig. 7.2.3). Subsequently, prevailing winds relocated most of the mobile weed biomass into three strategically positioned sheltered bays (Waiya, Thruston and Hannington) to the north of the Ugandan sector of the lake. Once in the sheltered bays, the water hyacinth biomass was rarely, and if at all, only partially, evacuated. These bays were, therefore, referred to as "water hyacinth storage bays". Weed biomass was accumulated and confined in these bays from about 1992 to 1997. The temporal water hyacinth production and storage capacity of a number of sheltered bays in northern Lake Victoria in Uganda are illustrated in Table 7.2.1. The values given are estimates of water hyacinth cover abundance. The rate of accumulation of water hyacinth in the three storage bays and in the main production bay (Murchison), are plotted in Fig. 7.2.4. The dynamic relationship between weed production and relocation for storage is clearly illustrated.

The initial accumulation rate of mobile water hyacinth cover in sheltered bays was apparently facilitated by availability of nutrient reserves. For example, in Lake Victoria, Uganda, mobile water hyacinth initially expanded faster in Murchison and Macdonald bays than in other bays such as Thruston and Hannington (see Table 7.2.1). However, weed cover estimates in some of the protected bays such as Macdonald and Pringle, continued to decline over time, indicating diminishing water hyacinth proliferation trends. Subsequent research indicated that the decline in water hyacinth cover was due to the relatively low stocks of essential nutrients especially phosphorus (see last column of Table 7.2.1). Sustained prolific water hyacinth production was maintained only in Murchison Bay, which registered by far the highest content of phosphorus. Sustained high weed production rate in this bay was facilitated by the constant input of municipal effluents from the City of Kampala.

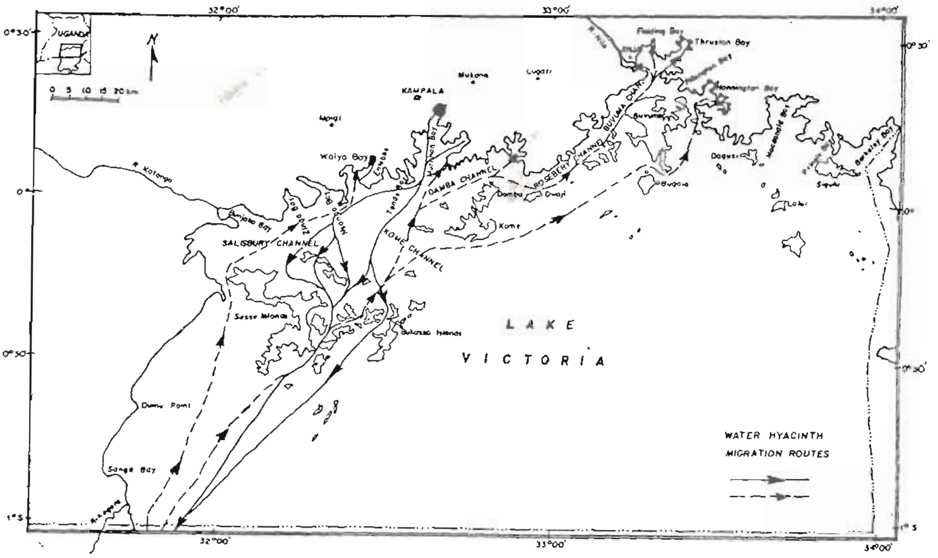

Fig. 7.2.3. Water hyacinth migration routes from the production bay (Murchison) to the storage bays (Thruston, Hannington and Waiya). Redrawn from Schounten *et al* 1999).

Infestations of water hyacinth in the Kagera River are distributed through most of the river course. Most other rivers that flow into Lake Victoria such as the Mara, Kuja and Migori have water hyacinth infestations only in the delta zones. These portions of the rivers are centers of active weed proliferation, whose intensity increases markedly at the onset of the rainy season in response to increase in the nutrient load in the water flushing the catchments.

Table 7.2.1. Changes in cover abundance (ha) of mobile water hyacinth in 'production' and 'storage' bays in northern Lake Victoria - Uganda.

Location (Bays)	1994	1997	1998 (May)	1998 (October)	1999	2001	Mean SRP (μgL^{-1})
MurchisonÅ	877	490	100		<2	10	425
Namirembe	ND	ND	ND	ND	ND	4	92
Waiya*	3	80	140	20	<1	<0.5	7.8
Thruston*	108	790	800	30	<1	<1	9.7
Hannington*	96	304	750	300	<1	<1	12.0
Macdonald	13	4	<2	<2	<1	<1	12.5
Pringle	15	5	<1	<1	<1	<1	14.5
Total cover	1,112	1673	1, 793	353	<8	<18	

Å Major production centre; * Major storage bays; ND = Not determined.

Proliferation of water hyacinth in Kenyan and Tanzanian waters

Rapid proliferation of water hyacinth in the Kenya waters of Lake Victoria occurred in the nutrient-rich bays such as Kisumu, Kendu, Nyakach and Homa (EAC 1999). Maximum water hyacinth cover in the Kenya sector of the lake, most of it mobile, was estimated at 6,000 ha late in the 1990s. Extensive distribution and proliferation of water hyacinth in the Tanzanian waters occurred along the eastern sheltered zones such as Mara Bay, Bauman Gulf, Speke Gulf, as well as in Emin Pasha Gulf and Rubafu Bay to the south (EAC 1999). The maximum estimate of that infestation was put at 2,000 ha, in the late 1990s. Most of the water hyacinth was mobile.

Impacts of water hyacinth in the Lake Victoria Basin

Infestations of water hyacinth in the Lake Victoria Basin inflicted socio-economic, environmental and ecological impacts. The general impacts of the weed, due mainly to the huge and often tightly packed biomass, included:

- Mechanical damage and /or obstruction by mobile weed biomass;
- Exclusion of light and dissolved oxygen from the water environment under tightly packed weed mats;
- Depletion of dissolved oxygen, release of toxic gases and fine debris due to continuous death and decomposition of dead weed biomass.

All the three generalised factors contributed to both the socio-economic and environmental impacts of water hyacinth in the Lake Victoria Basin outlined below.

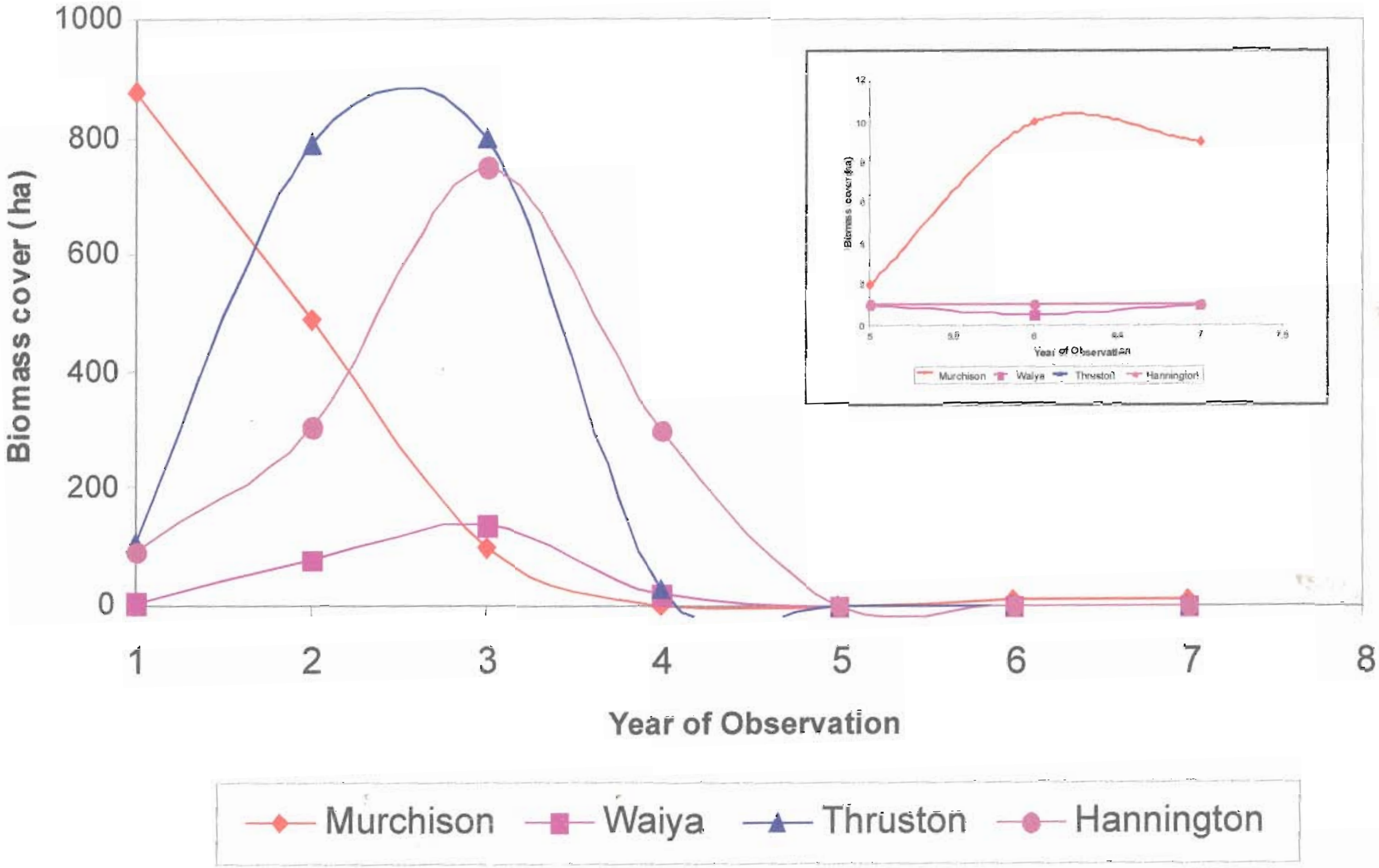

Fig. 7.2.4. Trends in distribution of water hyacinth cover (ha) in major production storage hot spots (bats) of Lake Victoria between 1994 and 2000 and (insect) magnified trends from 1999 to 2000.

Socio-economic impacts

The major negative socio-economic impacts of water hyacinth affected a variety of activities including fishing, water transport, water supply, generation of electricity and recreation (Odongkara 1995, 1997). Lakeside people as well as the different types of shoreline establishments were affected by stationary and mobile weed mats, through obstructed access to the lake at watering points, landing beaches, fishing grounds and along transport routes. Smothering and carrying away fishing gears by mobile water hyacinth caused serious economic losses, which often involved entire sets of the gears. Water filtration facilities at large-scale water abstraction plants were clogged or disabled when infiltrated by fine fragments of decomposing weed debris. More frequent servicing and replacement of water pump filters blocked by the fine debris was essential. Removal of debris, colour and unpleasant odours imparted to raw water by decomposing water hyacinth considerably increased the total bill for water purification and this was passed on to the consumer.

Hydroelectric power generation facilities were also affected. Physical extraction of water hyacinth biomass from Owen Falls Dam (Nalubaale Dam) imposed additional costs to the plant. Increase in frequency of cleaning the gate screens blocked by water hyacinth resulted in additional costs as well as loss in power generation time. Servicing of the cooling system for the turbines, which was often blocked by fine weed debris also resulted in extra costs as well as loss in power generation time. Various other industries incurred subsequent losses in production due to increase in the frequency of load shedding. Recreational facilities along beaches were also often smothered by the weed or fowled by deposits of mud and decaying water hyacinth debris. The impacts often involved loss of resources or necessitated considerable unplanned investment.

Environmental and ecological impacts

Information collected by scientists revealed negative environmental/ecological impacts that included displacement of biodiversity mainly through degradation of water quality and smothering of habitats by extensive, permanent water hyacinth cover. The water under the interior of extensive stationary mats of water hyacinth was virtually devoid of oxygen particularly late in the night and early morning (Willoughby *et al.,* 1993). The thick surface cover of the weed restricted diffusion of atmospheric oxygen into the water while the decay processes of dead weed debris depleted most oxygen accumulated during the day. Diffuse light, and poor water quality under conditions of decomposing water hyacinth debris reduced or eliminated growth of algae and aquatic macrophytes (and hence photosynthesis); and hence excluded most biodiversity dependent on dissolved oxygen. Extensive stationary mats and temporarily resident mats displaced fish and other animals from inshore nursery and feeding habitats. Refugia for biodiversity, originally provided under the native macrophytes were lost

(Willoughby *et al.* 1993; Willoughby *et al.*, 1996). On the other hand, large numbers of the typically low oxygen-tolerant invertebrate taxa such as chironomids and annelids flourished in environments with stationary water hyacinth (Wanda 1997, 2001).

Positive impacts of Water hyacinth infestations

Some water hyacinth infestations in Lake Victoria were associated with positive impacts. The main socio-economic reward was job opportunities for manual weed biomass removal at landings, where economic establishments and communities paid for labour. Considerable side benefits were obtained when hand tools and protective wear provided by government for water hyacinth removal, were also used for general maintenance of cleanliness at the beaches. Increased catches of fishes like the lungfish and catfish were realized at stationary fringes of water hyacinth. Positive environmental benefits were realized mainly through enhanced availability of refugia and feeding centers for fish and various other aquatic fauna at narrow stationary fringes of the weed, whose roots were regularly flushed with well-oxygenated water. Such water hyacinth fringes were rich in a variety of biodiversity including encrusted algae, and various invertebrates (Wanda, 2001). For some organisms like algae, invertebrates, the juvenile and the smaller fishes e.g. Haplochromines, the zone offered an ideal environment food and shelter from predation (Willoughby *et al.*, 1996). It was expected, therefore, that the open water interface of even the mobile water hyacinth mats was a haven for biodiversity similar to that associated with the narrow well-oxygenated stationary fringes.

Management of Water hyacinth in Lake Victoria Basin

Discussion on the challenges to manage water hyacinth in the Lake Victoria basin is largely limited to the experience in Uganda. The process to manage water hyacinth in Uganda evolved systematically through establishment of institutional arrangements; formulation of a weed control strategy; development and verification of weed management options; and implementation of the control strategy (Orach-Meza 1995; NARO, 2002). A regional approach to the management of water hyacinth on Lake Victoria was later formulated (EAC 1999).

Establishment of institutional arrangements

The Ministry of Agriculture Animal industry and Fisheries (MAAIF) coordinated the process to establish an institutional arrangement for the control of water hyacinth in Uganda. A National Taskforce on Water hyacinth Control (NTWC), composed of senior professionals from government institutions and other agencies affected by water hyacinth, was constituted in 1992 to formulate a strategy to control water hyacinth and oversee its implementation. The National Agricultural Research Organization (NARO) coordinated the NTWC. A Steering Committee on Water hyacinth (SCW), based in the office of the Prime Minister was subsequently formed to provide top-level political support and guidance to the water hyacinth control process. In turn, a subcommittee of the Agricultural Policy Committee - the Agricultural Policy Sub-committee on Water hyacinth (APSWV) - was constituted to co-ordinate water hyacinth control processes and act as a link with the SCW. Later, a Water Hyacinth Unit (WHU) was formed in MAAIF to supervise and co-ordinate implementation of Water hyacinth management. Various research institutes of NARO assisted by other national research institutions carried out all associated research.

The Water hyacinth control strategy

The NTCW formulated an Action Plan for the control of the water hyacinth, which emphasized integration of biological control as the sustainable option, with selective physical (manual and mechanical) weed removal for immediate relief at various facilities and installations. The possible use of herbicides to control water hyacinth was left open, pending efficacy and Environmental Impact Assessment (EIA). The Committee also recommended the immediate actualisation of manual removal as an initial measure to alleviate weed biomass impacts at vital economic installations and access routes (hydro power generation facilities, water abstraction centers, landing beaches, and wagon ferry terminals). These recommendations defined the technical roadmap towards water hyacinth control in Uganda.

The research institutes of NARO, assisted by scientists of the National Water and Sewage Corporation (NWSC) and Makerere University, carried out bench-scale and pond experiments to verify the efficacy and environmental friendliness of various candidate herbicides for possible control of water hyacinth. These studies were eventually integrated into a full EIA on the use of herbicides. The results of the EIA were, however, deemed inconclusive and use of herbicides to control water hyacinth was shelved. Tests were also carried out, at the request of Kenya and Tanzania, to demonstrate the specificity of two biological control weevils, *Neochetina bruchi* and *Neochetina eichhorniae*. The tests were conducted on common commercial and food crops in the region. The results opened the way for the release of biological control agents on Lake Victoria.

Implementation of the Water hyacinth control strategy

The practical steps taken in Uganda to control the proliferation of water hyacinth were systematic and deliberate. Manual weed removal by lakeside people was popularised through sensitisation and facilitated with hand implements and protective gears provided by the Government of Uganda. Initially, manual weed removal was the only available control measure at small landings and in approaches to landing beaches through wetlands. Mechanised water hyacinth removal was subsequently implemented at vital economic installations such as the Nalubale hydroelectric power generation facility across the Nile River in Jinja , and at the Wagon Ferry Terminal at Port Bell Pier, Murchison Bay. Appropriately designed mechanical weed harvesters were used.

PLate 7.2.1. One of the strategies used to contain water hyacinth spread through awareness.

The environmental friendliness of managing water hyacinth using biological control weevils was evaluated and accepted by the authorities in Uganda. Two biological control weevils *Neochetina bruchi* and *Neochetina eichhorniae* were duly imported from Benin in West Africa and released into Lake Kyoga in 1993 (Ogwang and Molo, 1999). Weevil multiplication and specificity tests of the two biological control weevils were conducted on common commercial and food crops in the region (Ogwang and Molo 1997). Results of the specificity experiments opened the way for release of Biological control weevils in Lake Victoria by Uganda in 1995 and 1996, and by Kenya and Tanzania in 1997 and 1998 (Mallya 1999; Ochiel *et al.*, 1999)

Effective management by biological control and environmental stress

The establishment and multiplication of *Neochetina* weevils on mobile water hyacinth in the Ugandan portion of Lake Victoria, especially in the three water hyacinth storage bays of Waiya, Thruston, and Hannington, was realised within one year. Full impact, ostensibly due solely to the effects of biological control, occurred early in 1998, hardly three years since the introduction of biological control weevils. The progressive decline in the health and stature of the mobile water hyacinth led to severe deterioration in plant condition (Plate 7.2.2) followed by extensive decay of the underwater biomass, culminating into loss of mat cohesion, listing and widespread sinking of vast expanses of water hyacinth in the three collection bays, virtually overnight. At least 1,600 ha of mobile water hyacinth perished in the Uganda portion of the lake in that episode. The massive sinking occurred during the last quarter of the year (1998), when the annual thunderstorms tended to evacuate water hyacinth from the three storage bays and from Murchison Bay.

Plate 7.2.2 Comparison between luxurious water hyacinth (a) and frail weed mats (b) severely impaired by heavy infestation with biological control weevils *Neochetina eichhorniae* and *Neochetina bruchi* in Lake Victoria-Uganda.

The destruction of mobile water hyacinth in the Ugandan portion of Lake Victoria was widely attributed to the effects of biological control. However, careful evaluation of various dynamics of the weed in Lake Victoria strongly indicated that stressful effects of various environmental and hydrological processes in the large lake facilitated the rapid establishment of biological control weevils and speeded up onset of the dramatic debilitating impacts on the water hyacinth. The main stressful factors included the prolonged confinement of mobile water hyacinth in the storage bays for three to four years, under conditions of diminishing nutrients; and the annual migration of huge water hyacinth mats across the hostile open waters en route to the weed storage bays illustrated in Fig. 7.2.3. It is thought that the significant rise in lake level due to the heavy El Nino rains of 1997/1998 contributed to the destabilisation of the water hyacinth mats prior to the massive sinking.

The successful control of mobile water hyacinth in the Uganda sector of Lake Victoria using *Neochetina* weevils within three years after establishment of the control agents was unexpected, unprecedented and to many, unbelievable. Doubt was, however, discarded when a similar process of mobile water hyacinth control was observed in the Kenyan and Tanzanian portions of Lake Victoria in the year 2000.

Ecological succession and the control of stationary water hyacinth

Proliferation of water hyacinth into stationary fringes along the lakeshore culminated into the phenomenon of ecological succession whereby several native aquatic plants took root among the weed fringes, and progressively eliminated the water hyacinth. Several native plants such as *Polygonum* spp, various sedges including *Pycrius munditii*, the wandering jew *Commelina bengalensis*, and *Ipomoea aquatica* usually initiated the succession, followed by aquatic ferns and or hippograss (*Vossia cuspidata*) (Twongo *et al.*, 2002). Hippograss was usually the dominant climax vegetation. In some environments the sedge *P. mundtii* dominated the succession. Initially, hippograss appeared to co-exist with water hyacinth in a mutually beneficial association such that both plants extended their range along the lakeshore and out towards the open water. Hippograss obtained support and nutrients from the mud-laden substrate of the underwater biomass of water hyacinth, and provided extra cohesion to the mats. The mutual advance was more extensive in shallow environments such as bays that were sheltered from offshore winds. The eventual displacement of water hyacinth in the succession appeared to have been largely due to light-shedding when the leaves of hippograss formed a thick canopy above the weed (Plate 7.2.3), and to competition for nutrients.

Plate 7.2.3. Domination of hippograss (*Vossia cuspidata*) during ecological succession with water hyacinth (*Eichhornia crassipes*) in Lake Victoria.

Ecological succession was, therefore, the fourth factor (in addition to physical extraction by manual and mechanical means, environmental stress and biological control) that contributed to the control of water hyacinth in Lake Victoria. Out of the 2,200 ha cover estimate of stationary water hyacinth in Uganda in 1996, ecological succession was estimated to have displaced at least 70% by 1998. Its effectiveness was ranked second after biological control. Part of the remaining component of the stationary water hyacinth was dispersed by the high lake levels due to the El Nino rains of 1997/98, while the rest , especially within the sheltered bays, came under enormous grazing pressure from *Neochetina* weevils after the collapse of the mobile water hyacinth in these bays late in 1998.

Control of stationary water hyacinth in riverine environments associated with Lake Victoria (the Kagera, the Upper Victoria Nile and other affluent rivers) was not successful by 2002 (Twongo *et al.,* 2002). Biological control weevils were not firmly established in those rivers. On the other hand, extensive ecological succession involving hippograss, had effectively controlled the weed in the relatively slow flowing Albert Nile and biological control had also been effective in patches where ecological succession did not occur. Clearly, control of Water hyacinth in the riverine environments in the Lake Victoria Basin from where large quantities of the weed entered the lake, remained a challenge.

Impacts of control measures for water hyacinth

Each of the methods and processes whose combined effects led to the control of water hyacinth in Lake Victoria was associated with potentially detrimental socio-economic and environmental impacts. The removal of water hyacinth biomass from the lake, to be damped on land, had the potential to disperse weed propagules including seeds to other water bodies. Secondly, the large quantities of Water hyacinth at the damps were not only unsightly but also smelt awfully as the weed decomposed. Trials to utilize water hyacinth as compost in gardens, were apparently not very successful.

Ecological succession by native plants especially hippograss had both positive and negative impacts. The most notable positive impact was the eventual suppression of the weed (Twongo *et al.*, 2002). Secondly, The displacement of stationary water hyacinth with stands of hippograss improved water quality (notably the content of dissolved oxygen), species richness and food-chain dynamics. Environmental quality and biodiversity were expected to improve further as disintegration of hippograss-dominated fringes progressively collapsed. Two negative impacts were, however, noted when the climax vegetation stands were dislodged from the shoreline. Resurgence of water hyacinth was predicted to occur (and did eventually occur in some bays) in the exposed original water hyacinth nurseries. The more troublesome impacts, however, were socio-economic. Floating islands of hippograss destroyed set fishing gears such as gillnets, smothered macrophyte beds and fishing grounds; and blockaded landing beaches and transport lanes. These impacts were severe on Lake Kyoga in Uganda, where ecological succession was extensive and the most important process in the control of water hyacinth.

The effects of biological control lead to the collapse and sinking of about 1,600 ha of water hyacinth biomass in the Ugandan portion of the lake in 1998. In the year 2000, much larger expanses of the weed sunk in the Kenyan portion of the lake due to similar effects. Scientific experiments made by FIRRI in Thruston Bay, one of the weed storage centers in the Ugandan portions of the lake, following the sinking of the weed biomass, demonstrated a significant temporary decline in dissolved oxygen and elevation of soluble reactive phosphorus at the bottom of the bay . The sunken biomass facilitated increased diversity and abundance of decomposer macro-invertebrates especially annelids, accompanied by intense algal productivity, zooplankton production and a significant increase in fish species richness and production. The study did not rule out possible elevation of the stocks of Phosphorus over the long term, due to the sunken weed biomass.

Prospects for water hyacinth resurgence and recommendations

The distribution and quantity of water hyacinth in Lake Victoria significantly reduced after the year 2000. Resurgence of the weed occurred in all the three riparian states (NARO, 2001) but rapid multiplication of the residual stocks of biological control weevils successfully contained it, except in the nutrient-rich hotspots such as Murchison and Bunjako bays in Uganda and Kisumu Bay in Kenya. The resurgence was, therefore, a reminder that continued nutrient enrichment of Lake Victoria could trigger fresh widespread infestation of the lake with water hyacinth and other invasive weeds. Of more urgent concern was the fact that management measures so far instituted in the Lake Victoria basin had not yet controlled the weed in the rivers especially the Kagera and the Victoria Nile. Much more effort was, therefore, required towards achieving comprehensive and sustainable control of water hyacinth in the lake basin. The following recommendations were made.

It was recognized that nutrients especially phosphorus and nitrogen were essential for the proliferation of water hyacinth. Research to identify nutrient sources, routes and dynamics of the essential nutrients especially Phosphorus, were essential to the formulation of sustainable nutrient management strategies.

Water hyacinth in rivers that flow into Lake Victoria ends up in the lake as live or dead biomass. Both forms of the weed had negative environmental impacts on water quality, which in turn influenced lake productivity and biodiversity. Research to develop effective strategies to control riverine water hyacinth should be a priority. An effective early warning surveillance mechanism for the possible resurgence or invasion of water hyacinth and other waterweeds in the Lake Victoria Basin was lacking. Such a system, which should involve grass-root communities, NGOs and key institutions, and be linked to standby control options, would facilitate timely identification of, and response to invasive weed resurgence or invasion.

Water hyacinth in Lake Victoria Basin was known to undergo polymorphic transformations (Twongo *et al.*, 2002). One of the morphs was a dwarf form capable of prolonged existence in difficult environments as a strategic seed reserve. When favourable conditions return, the dwarf form readily transforms into a highly prolific growth form, which then facilitates rapid weed dispersal. Understanding of the environmental factors that facilitated these morphometric transformations was identified as key to improved management strategies for water hyacinth in the basin.

The flow of information about water hyacinth and its control across borders, and even among stakeholders within a given country in the Lake Victoria Basin was woefully slow. Deliberate effort to promote the sharing of information on various developments in the management of water hyacinth and other invasive weeds in the basin and beyond was strongly recommended.